Art. V.—*Preliminary Account of the Glacial Deposits of Bacchus Marsh.*

(With Plates X, XI and XII.)

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[Read July 14, 1892.]

The subject of glaciation is one that is always of the greatest scientific interest. Its important bearings on the questions of climate, past and present, and on the problems connected with the evolution and distribution of plants and animals, render it a field where the astronomer, geologist and biologist may meet on common ground. The subject has received its fair share of attention in the Northern Hemisphere, in Europe, America, and Asia, but in the Southern Hemisphere, where the evidence of past glaciation is not so conspicuous, comparatively little has been done in this direction. Any evidence of past ice-action in Australia that may be discovered is of peculiar value, on account of its bearing on the question of the probable cause of ice-ages.

The earliest reference to glacial action in Victoria is made by Selwyn in his work on the Geology of this colony. In this, a conglomerate is mentioned as occurring near Bacchus Marsh, and which contained boulders which he and Mr. (afterwards Sir) R. Daintree considered could only have been brought there through the agency of floating ice.

Mr. James Stirling, F.G.S., and Dr. Lendenfeldt, have described evidences of former extensive glaciation in the Australian Alps. To these discoveries reference will be made later on.

Mr. E. J. Dunn, F.G.S., has contributed two papers on the Glacial Conglomerates of Victoria—one read before the Royal Society of Victoria; the other, in which the first is incorporated, before the Australasian Association for the

Advancement of Science at the 1890 meeting. This conglomerate is described as occurring, among other places, at Bacchus Marsh, and is said to consist of material, the great bulk of which is derived from schistose and other ancient rocks and to contain pebbles, boulders and masses of from 20 to 30 tons weight. Granites, gneiss, schist, quartz-rock, sandstone, lydianite, agate, shale, porphyry, and jasper, &c., are said to occur in it. Many of the included stones are striated, and often flattened on one or more sides; others are well rounded, and others again are rough angular fragments. Erratic blocks of granite occur on the surface at Wild Duck Creek, near Heathcote.

Mr. Dunn is of the opinion that "no other conclusion can be arrived at than that floating ice has been the agent by which the material has been brought into its present position." "Much of the material," he says, "is foreign, and many of the rocks are not known to occur at present in this Continent anywhere near Victoria." He also considers the conglomerate at Wild Duck Creek to be very similar to the Dwyka glacial conglomerates of South Africa. Mr. Dunn's description is very general, and the evidence on which his conclusions are based is somewhat vague and wanting in specific detail.

Mr. T. S. Hall, M.A., has also given a short account of these deposits at Heathcote in the "Victorian Naturalist," (Vol. VIII, No. 2). He also considers the beds to be of iceberg origin.

Victoria is divided into two main areas by a continuation of the Australian Cordillera, known as the Main Divide, or Great Dividing Range. This extends from Forest Hill on the east to the Grampians on the west. In the eastern part of the south division we have the South Gippsland and Westernport Ranges, of which the Southern Spur forms a leading feature. West of Port Phillip we have the isolated Otway Ranges. The Main Divide reaches its highest elevation in its eastern portions, Mount Kosciusco being over 7000 feet and several other mountains over 6000 feet above sea level. Passing westwards the elevation gradually diminishes. The average elevation is about 3000 feet, but in some places it sinks to 1000 feet above sea level. The average distance from the coast is about seventy miles. There are three main drainage systems—(1) The Murray System, north of the Divide; (2) The South Eastern or Gippsland System, south of the Main Divide and east of the southern spur; (3) The South Western System, south of the Main Divide and west of the Southern Spur. The Main Divide, according to Murray, is a "longitudinal area of Lower Palæozoic rocks, with granite and trappean intrusions." These may be overlaid by, or flanked by Upper Palæozoic, Mesozoic, and Tertiary deposits.

The Bacchus Marsh district is situated about midway between Melbourne and Ballarat, and thus belongs to the South West Drainage System. The principal streams in the locality are the Werribee and its tributaries, the Myrniong and Korkuperrimul Creeks and the Lerderderg River. The town of Bacchus Marsh is picturesquely situated in a broad extensive valley 343 feet above the sea, and which has probably formed the basin of an ancient lake. On the one side runs the Werribee, and on the other the Lerderderg, the junction of the two streams taking place about a mile below the town. From Bacchus Marsh the country gradually rises to the Dividing Range, only a few miles distant to the north. The rising ground between Bacchus Marsh and the Dividing Range is known as the Pentland Hills.

The so-called glacial conglomerates are well developed in this district and numerous sections exposed to view by the Creeks and various cuttings provide very favourable conditions for their study.

The first section we examined is situated on the Ballarat Road, about three miles on the Ballarat side of Bacchus Marsh, and is at a height of about 750 feet above the sea. The deposit exposed consists of a matrix of clay of a quite unstratified appearance, and of a somewhat variable consistency. It is tough and hard in places, while in others it is softer and less tenacious. The colour is an indefinite patchwork of white, yellow and purple. Through this matrix are scattered irregularly numerous stones of various sizes and sorts, rounded and sub-angular. These stones do not show the slightest trace of arrangement either in size or in position. Some of the stones are waterworn, but many present quite another and distinct appearance. These often show one or more flattened sides, while the edges and ends are frequently rough or sub-angular. Besides these peculiarities many show striated surfaces, the striæ generally running in the direction of the longest axis, but several sets of striæ can often be distinguished. Certain kinds of stones show striæ much better than others.

A hard fine grained argillaceous sandstone varying in colour from a very light to a darker green is the predominating rock-material, and this kind usually exhibits the most marked striations. Another common variety is a blue-black very hard quartzite. These, though commonly exhibiting flattened or facetted sides and angles, seldom show striæ, their surfaces being more often polished.

Granite often occurs though not so frequently as the other kinds of rock. The largest boulders are of this material. One taken from the cutting can be seen lying at the side of the road, which is well flattened on one side. The granite is generally considerably decomposed. At the top of the cutting a large angular fragment of sandstone occurs, while another piece can be seen at the base; whether the latter is *in situ* or not we have not yet determined.

The unstratified nature of this deposit, together with the peculiar nature and want of arrangement of the included stones, at once stamps it as of glacial origin.

A few feet back from the top of the cutting on the south side, an outcrop of white silicious sandstone occurs. We are inclined to think that the glacial deposit is banked up against this, really overlying it.

A short distance below the cutting a small lateral road joins the main one, and on this road, a hundred yards or so from the junction, another cutting exposes a good section. The material exposed is similar to that just described, but is of a more uniform purple colour. It is also somewhat harder. It is quite unstratified and contains numerous well striated stones. On the surface, on both sides of this cutting, glaciated stones are scattered about in great profusion and variety. This deposit apparently overlies sandstones and is continuous with that exposed on the main road.

Before making our next visit to the locality, we wrote to Mr. Charles Brittlebank, of Dunbar farm, near Myrniong, who, we were led to believe, could give us information in our researches. Mr. Brittlebank readily responded, and during our subsequent visits has rendered us much valuable aid. He has accompanied us on most of our expeditions and shown us much hospitality, while his intimate knowledge of the locality, as well as his keen powers of observation, have been of the greatest assistance to us. Mr. Brittlebank informs us that he found glaciated stones in this district four years ago. He thus appears to have been the first to actually prove the glacial origin of the deposits in question.

The valley of the Myrniong Creek for some little distance above its junction with the Werribee is cut through basalt and sandstones and conglomerates to a depth of over 600 feet. Good sections are exposed along this valley.

On the south side, about half a mile above the confluence of the two streams, a depth of over 100 feet of a material similar to that described on the Ballarat Road is exposed. It consists of a mass of yellowish white clay, quite unstratified, and in texture somewhat soft on the weathered surface, but much harder on being penetrated. Numerous stones of all sorts and sizes, from mere grit to boulders several feet in diameter, are scattered irregularly, and without any trace of arrangement throughout this clay. Among these stones, the principal varieties are those occurring in the cutting on the road already described. Chiastolite and other varieties of slate were found, together with quartz, bits of jasper, and a hard, red quartzitic sandstone. Most of these stones are sub-angular, often showing one or more smoothed and flattened surfaces, while the edges and ends are roughly angular; many are well striated and grooved in a characteristic manner. On some large boulders lying at the base of the cliff, the striæ and grooves are exceptionally well developed. This deposit can be traced up the valley for about a quarter of a mile above this point, when it thins out, and is seen to overlie and flank the sandstones through which the valley has been worn. It is overlaid by basalt known as the newer volcanic, and assigned to Pliocene age (Fig. 1).

On the other side (north) of the Myrniong Creek, but nearer its junction with the Werribee, the glacial deposit is again well shown to a depth of about 150 feet. It is much the same as that on the opposite side of the valley, and striated stones are numerous. This extends to within 200 yards or so from the junction of the two streams. It can be traced over the brow of the valley up to about the level of Mr. Brittlebank's house, about 350 feet above the Creek, and about 1100 feet above the sea. It then spreads out over the surface.

It would seem evident then, that the valley now occupied by the Myrniong Creek at this point at any rate is a very ancient one, and was at one time probably almost filled up by this glacial conglomerate. The sandstones and conglomerates through which the valley is worn, were set down as Upper Palæozoic by the Geological Survey; then, on the discovery of three species of Gangamopteris, Professor McCoy assigned them to Triassic times. Last year, more fossils were obtained. These were somewhat fragmentary, but Sir Frederick McCoy thinks he can identify Schizoneura and Zeugophyllites, indicating a lower Triassic age for the rocks in question.

After the glacial material had been deposited in this ancient valley, it was overflowed by basaltic lavas of Pliocene age. Whether the older basalt of Miocene times also overflowed this valley previously to the former, we cannot say with certainty. We have seen no evidence of it at any rate. Since Pliocene times the valley has been again denuded to its present condition.

From the general characters presented by the so-called glacial conglomerates, we were much inclined to the opinion that they would turn out to be, not an iceberg-drift, but in reality till, or boulder-clay—in fact the ground moraine of ancient glaciers. These characters may be summed up as follows:—(1) The unstratified nature of the clayey matrix. (2) The number and variety of the included stones. (3) The striated and glaciated aspect of many of these stones. (4) Their total want of arrangement. In fact, these deposits bear such a striking resemblance in every way to the till of Scotland and elsewhere in the Northern Hemisphere, that it can hardly be doubted that they are of similar origin. Corroboration was therefore to be sought for in the shape of roches moutonnées, or shattered rock surfaces beneath this deposit.*

In the valley of the Myrniong Creek, opposite the section described as occurring on the south side, can be seen rounded, hummocky-looking masses of sandstone, the appearance of which is very suggestive of glacier action. It is very probable that the glacial conglomerate not long since covered these rocks, and thus protected them during a long period from the effects of weathering. It must also be remembered that the glacial conglomerate itself must have been protected for a considerable time by the basalt. The sandstone is hard and massive, and is just the kind of rock on which the abrading and rounding effect of glacier ice would be well represented. Certainly, striæ and grooves are absent, but

* Having had opportunities of observing the till and other phenomena of glaciation in Scotland, Ireland, and Switzerland, I can vouch for the striking resemblance of our glacial deposits to the boulder-clay of the Northern Hemisphere.—Graham Officer.

these may have weathered away. In many parts of the Scottish Highlands, where the whole country shows the rounded and flowing contour characteristic of ice-action, it is often very difficult to find actual scorings and grooves.

Some little distance further up the Creek a section has been exposed by the stream, showing some feet of a hard unstratified material containing striated stones. This was much harder than any we had previously examined, and was traversed by joints. It was seen to be clearly overlaid by sandstones, the junction between the two being very distinct, there being apparently an unconformity. Here a fault occurs through the sandstones and the underlying material, the displacement being about seven feet, and the hade at a high angle. There would seem to be no doubt that the overlying sandstones are continuous with the surrounding ones, which, as we have seen, are probably Triassic. So now it seemed probable that we had to deal with two glacial deposits.

At the junction of the Myrniong and Werribee, the latter stream is seen to be flowing over the highly inclined and sorely denuded edges of Lower Silurian rocks, here consisting of very hard, fine-grained, well stratified sandstones. On the weathered surface the colour of these is of a patchy yellow rusty colour, but on the fractured fresh surface they are of a light greenish white, or light slaty white colour. On proceeding up the Werribee from the junction, we found ourselves walking over another kind of material, which was seen to rest unconformably on the Silurian rocks, which it closely resembles in colour. The Creek has cut its way through this to the Silurian, so that on the floor of the river course one walks now on a few feet of Silurian, and now on this other deposit, while sections are exposed on both sides of the stream. This deposit consists of an exceedingly hard clayey material, through which are scattered stones and boulders of considerable size, of granite, quartzite, fine-grained hard sandstones (very similar to the underlying Silurian), and quartz. Nearly all these present the flattened sides, and striated and grooved surfaces characteristic of ice action. The stones and boulders at this point are very numerous, and the scorings and scratchings exceptionally well developed. This conglomerate resembles those already described, in the absence of any appearance of stratification, the character of the included stones, and the total want of arrangement of the latter. In fact, it cannot be distinguished from boulder-clay or till. However, it differed from those we had yet examined, except the last described, in being so excessively hard and tough, and in being traversed by numerous joints. Till one has actually tried, it is impossible to give an idea of the difficulty of extracting a stone from this material, which will only come away in small angular fragments, in a manner that is peculiarly exasperating. On the north side of the Creek, a short distance from the junction, a section of a similar deposit is exposed, which presents a somewhat stratified appearance; striated stones occur irregularly through this, but they are not so numerous as on the opposite side of the Creek. The appearance of stratification presented may possibly be due to pressure. It is overlaid by basalt.

On proceeding up the Werribee a few yards further on the south side we found a small cliff, where the junction of the conglomerate with the underlying Silurian could be well seen in section. Here was a place where, if the conglomerate were a true till, we might expect to find the underlying rock smoothed and striated, or else shattered. The section exposed showed the Silurian rocks rising in a hummocky way, and closely overlaid by the conglomerate. A closer inspection revealed a certain rounded and facetted appearance, that was very suggestive of ice action. Having found a place where the overlying deposit was thinner than usual, we resolved to clear away a portion, and after some difficulty and hard work succeeded in laying bare a portion of the rock below. We were amply rewarded for our trouble. The Silurian rock presented in a beautiful manner a well smoothed and striated surface, with deeper parallel grooves, all running in a north and south direction, and of the glacier origin of which there could be no doubt whatever. The Silurian strata here dip west, at angles of from 50° to 60°. So it will be seen that the strata are cut across at right angles to the dip, in fact in the direction of the strike. It is quite impossible that this can be due to the action of the Creek, or indeed to the action of water at all. The striæ and grooves point right across the Creek. The contiguous portions of the overlying deposit, when removed, were found to retain perfect mouldings of the grooves and striæ beneath.

This striated and grooved rock surface, taken in connection with the nature of the overlying deposit, leaves no room for doubt as to the glacier origin of the latter, and that it is a true till, or moraine profonde. This till can be traced down the Werribee to its junction with the Myrniong Creek, and a little way beyond on the latter Creek. It here is apparently overlaid by the Triassic rocks. With heavier tools than we had at our disposal, and a little more time, it would not be difficult to remove more of the till from the underlying Silurian, and thus lay bare more of the moutonnée surface.

A few days after this discovery, we received a letter from Mr. Brittlebank, stating that he had found a further example of roche moutonnée at the lower end of the Werribee Gorge, nearly two miles below its junction with the Myrniong. On our next visit, we accordingly proceeded to the spot, and examined the rocks in question.

The Gorge has been cut to a depth of over 600 ft. through a mass of Silurian rocks, flanked by the Triassic sandstones and conglomerates, the former having formed a ridge or island in the Triassic sea or lake (Fig. 1). The Silurian rocks here consist of slates, finely laminated shales, and hard quartzitic sandstones; quartz veins are frequent, and a dyke of porphyry also occurs. The strata are inclined at the usual high angles, being often almost vertical.

At the place indicated by Mr. Brittlebank we found the till again overlying the Silurian. Here, it presents much the same appearance as that last described, glaciated stones and pebbles being frequent. At this point, at a spot where the till was only about a foot thick, Mr. Brittlebank had laid bare a portion of the underlying rock. An example of roche montonnée was thus exposed to view, which was even better than the one first discovered. More of the overlying deposit was now removed, and a greater surface of the underlying rock uncovered, this being an operation of some difficulty. The surface exposed presented the appearance of three smooth parallel ridges, well scored and striated, with well rounded grooves six or more inches deep between. Here, as before, the striæ and grooves run north and south, in the direction of the strike, and right across the river (Pl. XI). In several places, the rock has been fractured at right angles to the groovings. Photographs of these were obtained. This was by no means the only spot in this locality where roches moutonnées were found. A short distance further up the Creek can be seen a rounded hummock of Silurian rock, which has been denuded of the overlying till. The effects of weathering have obliterated all striæ and grooves, but the rounded contour still remains. In several other places small portions of the till were removed, and a striated and grooved surface invariably exposed, the direction of the striæ being still constant. The till here is about ten or twelve feet in thickness, and is distinctly overlaid by the Triassic rocks. On the opposite side of the river (south side), a good section is exposed. The till is again seen resting on the Silurian rocks, which here also, as seen in section, appear to have been subjected to the action of ice (Pl. XII). The strata are nearly vertical. The till here is seen to thin out, forming a wedge-shaped mass. It is overlaid by the Triassic rocks which, below the lower end of the wedge, rest directly on the Silurian. The till and overlying formation extend a short distance up the Creek from this point, when they terminate against the uprising ridge of Silurian strata.

There would seem to be little doubt that the Triassic rocks overly the till unconformably. It will now be seen that there are two distinct glacial deposits. Of these, one is overlaid by the Triassic sandstones and conglomerates, and is undoubtedly an ancient till, or moraine profonde; the other overlies the Triassic rocks and is similar to the lower till, except that it is not so hard nor so traversed by joints, which is hardly a matter for surprise.

Numerous well striated stones and boulders are scattered over a great part of the surface between the Ballarat Road and the Myrniong and Werribee streams, up to an elevation of over 1100 feet above the sea. These stones can be traced flanking the ridges that overlook the Werribee. At a point opposite the Gorge, at the lower end, the stones are especially numerous and very well striated. In addition to the commoner varieties, a hard semi-crystalline sandstone, of a dark pink colour, occurs. The stones here overly the Triassic sandstones, and can be traced along a small lateral gully right down to the Werribee. The deposit from which they come is exposed at various points along this gully, and is quite similar in its unstratified nature, and in the irregular arrangement of the included stones to that described before. In places it presents a very hard texture, sometimes somewhat resembling the till below the Triassic rocks, in other places it is softer, but in several places where its junction with the underlying sandstones could be seen, it was so invariably hard and thick that we could not clear any away so as to expose the underlying rock. However in places, as seen in section, the latter presented a rounded appearance that was very suggestive of ice action.

At the intake of the Bacchus Marsh water supply on the Werribee, about a mile below the Gorge, where the valley is very broad, a splendid section of a till-like deposit is exposed; there being over 70 feet. The matrix is a yellowish-white clay, very tough and hard, and stones and boulders of the usual kind are scattered through it in a pell-mell fashion, with no trace of arrangement. There is no stratification, but irregular bands occur here and there, sometimes lenticular in form. These bands are in some cases of a fine sandy material; others consist of minute angular fragments of much the same nature as the rest of the deposit, but coarser. These bands are only about eighteen inches or two feet in thickness, and seem to have been formed by the intermittent action of running water. Similar bands and lenticular patches of sand and other material occur frequently in the till of the Northern Hemisphere, having been formed by the action of sub-glacial streams. We have not yet been able to determine definitely the relations of this deposit, but from its nature and position, as well as its great thickness, we incline to the opinion that it belongs to the upper glacial deposit. It occurs again about half a mile further down the river, where good sections of it are exposed. It here does not contain nearly so many stones, while those that do occur are generally small, otherwise it is similar to that last described. We have not found the deposit between this point and Bacchus Marsh along the Werribee.

About four miles up the Korkuperrimul from the bridge on the Ballarat Road, a glacial conglomerate is again met with containing numerous typical glaciated stones. The matrix is exceedingly hard and devoid of stratification. In places, when looked at from one point of view, an appearance of a somewhat irregular stratification can be seen. However, a more careful examination reveals the fact that what are apparently lines of stratification, are in reality curved division-planes, which are probably due to shearing stresses. At one place in this section a departure from the usual irregular disposition of the stones may be observed. The stones are arranged in a sloping fashion, along an inclined plane. This arrangement is sometimes met with in the till of the Northern Hemisphere. At this place also a boulder, about eighteen inches long and somewhat pear-shaped, can be seen resting in the matrix in a vertical position. Now, if such a boulder were dropped from an iceberg, we might expect it to remain in an upright position in the soft clay, but if so, we should certainly expect to find the clay indented beneath it. Of this, there is not the slightest indication.

A little further up the Creek another section is exposed. Here our till-like deposit rests on massive sandstone, but we were unable to remove sufficient of the former in order to expose the surface beneath. At one point, however, a somewhat remarkable feature occurs. In the sandstone is an oblique gap about four or five feet deep, as if a block had been torn out. This cavity is filled with the overlying material, and two or three flattened and striated stones rest on its lower *side* (not *bottom*). It is difficult to conceive how icebergs could have deposited stones in this manner, while on the other hand it is readily explained on the glacier theory.

The locality between this place and the large quarry, about two miles further down the Creek, we have not yet examined. Between this quarry, situated on the north side of the Korkuperrimul, and the bridge on the Ballarat Road, the valley in which the Creek flows follows approximately the axis of what has once been an anticlinal fold of the Triassic sandstones. Opposite the large quarry, the valley is a little to the right of this axis. Between this large quarry and the Creek, striated stones are numerous. A small lateral gully exposes sections. One of these shows a somewhat loamy clay, in which are irregularly imbedded large angular fragments of sandstone, in appearance very like the underlying rock. Large granite boulders, quartzite, slate, quartz, and fragments of jasper also occur, many showing flattened and striated surfaces.

On the Creek opposite the quarry, a cliff of about 60 feet of the glacial deposit is exposed. It is very similar to that described on the Ballarat Road. It rests on sandstones, the broken ends of which can be seen protruding from the base of the deposit, which towards the top, presents a somewhat stratified appearance. On the opposite side of the Creek, high cliffs of basalt (newer) occur. This has evidently filled up the valley at this place, probably covering the glacial deposit and having since been denuded away to its present state.

Several hundred yards further down the Creek, on the right hand side, a section exposed shows a few feet of an unstratified material bearing striated stones, and overlaid by very irregularly stratified tumultuous-looking sandstones. These sandstones are very probably simply beds associated with the glacial deposit. This is indicated by their tumultuous appearance, and by the fact that we found several well scored stones in them. Moreover, a small patch of a material similar to that beneath occurs intercalated with them. The basalt is banked right up against this, the line of junction being almost vertical. The whole mass probably formed a ridge in the valley at the time the basalt overflowed it. Striated stones can be traced for about a third of a mile further down this valley, on the right hand side, being overlaid by basalt (Fig. 2) The characteristic stones of the glacial deposit can be traced along the hills flanking the valley on the left. At one spot, between the big quarry and another smaller one further down the valley, a conglomerate occurs, which consists of a loamy matrix, in which are scattered angular fragments, in all positions, of soft sandstone. This rests on the denuded edges of well stratified Triassic sandstone, from which the fragments have apparently been derived.

Some distance further on, a small quarry occurs in the Triassic sandstones, which here dip E.S.E. about 35°. The glacial conglomerate can be traced to about 200 feet above the Creek, and in the quarry can be seen in section resting on the sandstones to a depth of about five feet. On the left hand side of this section, the junction is very marked, while tracing it to the right, it becomes very indefinite by the disintegration of the sandstone. This section is at right angles to the dip. At the same quarry, another section is exposed at right angles to the former. This exhibits remarkable and important features. Beginning at the lower end of the section, a pell-mell accumulation of rough angular and rounded blocks, up to eighteen inches and two feet in diameter, embedded in a loamy matrix, is seen overlying soft purplish stratified clays or shales. The latter are much broken up and disintegrated at their junction with the overlying deposit. Angular blocks of sandstone in every conceivable position are mixed up in the ruin, and in fact a definite junction it is almost impossible to distinguish. Further along the section, this mixed material merges into a purplish mass of clay, overlying broken and shattered sandstones. (The shales and sandstones are of the same formation.) This purplish clay, which is evidently derived from the shales, presents the appearance of having been pushed over the sandstones, angular blocks of which are scattered through it. A little further along, a large irregular fracture in the sandstone occurs, being seven or eight feet deep. This is literally stuffed with stones and boulders of the various kinds met with in the glacial conglomerate. Many of these show flattened and striated surfaces. A granite boulder, over a yard in diameter, is jammed into the bottom of this fracture, while broken and angular fragments of the sandstone are also scattered through it, the whole being imbedded in a loamy clay-like material, which seems to have been squeezed into the fracture (Fig. 3). At several other sections exposed in this quarry, similar appearances can be noted. The sandstone has been fractured, and the glacial material literally injected into the cracks and fissures. Several striated stones were picked out from one of these fissures.

It will be seen that, as in the case of the Myrniong Creek, the glacial deposit lies in an ancient valley of denudation. It was probably overflowed by Pliocene basalt, which would thus be the means of protecting the underlying formations during a considerable period. We could not find any more traces of the glacial material between this place and the Werribee.

This concludes the evidence we have so far collected, and it all points irresistibly to the conclusion, that glacier-ice has been the agent by which the effects described have been accomplished. No iceberg theory will account for the facts presented at the quarry. How will such a theory account for the fracturing of the underlying rocks, and the ramming of the fractures with large erratic boulders and the material in which these boulders are imbedded? On the other hand, these are facts which are readily explained on the glacier hypothesis. In the Northern Hemisphere shattered surfaces are frequently met with below till. In his "Great Ice Age," p. 16, Prof. James Geikie says:—"Soft sandstones and highly jointed rocks . . . often show a broken and shattered surface below till; sometimes, indeed, thick sandstones appear 'broken up' to a depth of many feet below boulder-clay, the coarse angular débris shading gradually into till of the normal type." This corresponds exactly with the features presented at the quarry, where the sandstones are soft and easily disintegrated. Cases in Scotland and elsewhere in the Northern Hemisphere are not uncommon, where the shattered surface of the underlying rock is "stuffed" with erratic stones and boulders.

The conclusion, then, to which we are led is, that the deposits we have been considering constitute a true till, or moraine profonde. This is borne out by further considerations. It is worthy of note, that the stones occurring in this till, at the quarry we have been speaking about, are not nearly so well striated as those occurring in the region of the Werribee Gorge. In the former case, we have seen that the underlying sandstone is very soft, and would not striate stones well; on the other hand, the underlying rocks in the region of the Gorge are much harder, consisting to a great extent of conglomerates, just the kind of rocks that would produce marked scorings on the stones of the till.

These are specific evidence against the iceberg theory. There are also more general arguments. These arguments have been used before to refute the iceberg hypothesis of the origin of the boulder-clay in the Northern Hemisphere, and they apply equally well here.

Mr. Dunn describes the so-called glacial conglomerate, besides being found at Bacchus Marsh, as occurring on both sides of the Dividing Range, at Wahgunyah, Rutherglen, The Springs, El Dorado, Wooragee, Tarrawingee, Baddaginnie, at various points on the road between Wangaratta and Kilmore, north east of Costerfield, Wild Duck Creek (west of Heathcote), underlying the auriferous deposits at Carisbrook and Creswick. South of the Dividing Range, it is met with about four miles east of Gordons, Barrabool Hills, and near Foster in South Gippsland. Thus it will be seen that the deposit is widely distributed, and it appears to be of considerable thickness, being over 100 ft. in several known instances.

It has been shown (Croll, "Climate and Time;" Geikie, "Great Ice Age," &c.), that the amount of material carried by icebergs is quite inconsiderable, and what is carried generally consists of rubbish and angular blocks that have fallen on the surface of the parent glacier. In the case of the ice-sheet that is at present desolating Greenland, the surface of the ice is very free from débris of any kind, and so it is quite a rare thing to find an iceberg shed from one of the vast glaciers of that country bearing any material at all. Yet a tremendous amount of erosion must be going on, and the eroded material is being accumulated beneath the ice as a moraine profonde, although prodigious quantities must be carried away by sub-glacial streams. Dr. Wright ("Ice Age in North America") calculates that from the great Muir glacier in Alaska over 33¼ million cubic yards of sediment is annually carried away by sub-glacial streams. Little, if any, of the sub-glacial material can be carried away by icebergs—a few stones, perhaps, frozen into the bottom of the bergs. The finer material carried away by streams from beneath these great glaciers must inevitably be stratified, and well stratified, as the quantity of material brought down must vary considerably from time to time. Even if much fine matter were carried by icebergs, it would inevitably be re-assorted by the water; the stones, too, would assuredly show some trace of arrangement.

In the deposits we have been considering, the absence of stratification and the total want of arrangement of the included stones, are their chief and most striking characteristics. Then again, in the great mass of the sections we have examined angular fragments are comparatively rare, except as we have seen, where the till rests on the underlying rock. So here again, we have a strong argument in favour of the glacier theory.

Further, these deposits are found up to a height of 1400 ft. at Ballan; so, to account for them on the iceberg theory, we would require a submergence of at least 2000 ft. to allow icebergs to float, and as icebergs can only transport material from higher to lower levels, it is quite impossible to account for the mingling of fragments of the underlying rock in the overlying till, at an elevation not exceeding 800 ft. above the sea. Besides, such a submergence would considerably diminish the area from which the deposits could be derived, and their extent indicates a large surface. Again, such a submergence would tend to produce climatic conditions which would be quite opposed to the production of glaciers, even were the astronomical conditions favourable. It must also be observed that, so far as we have seen, these deposits are quite unfossiliferous.

Mr. Dunn states that much of the rock material occurring in the till is not known at present to occur *in situ* on this Continent anywhere near Victoria. Daintree remarks that a granite occurs in the formation at Bacchus Marsh, which he had not observed south of Queensland. However, as he has not described this granite, it would be difficult now to identify it. We would reply to this that further search will probably reveal the sources of this material. The geology of Victoria has not been so fully worked out as to warrant us asserting that a certain kind of rock does not occur *in situ*. Then again, it must be remembered that these deposits are anterior—as we shall show—to the Miocene and Pliocene lava flows, and probably to the Miocene leaf-beds, so that, not to speak of the effects of denudation, a a great deal of the then rock surface is now concealed.

Of the various kinds of rock met with in the till in the Bacchus Marsh district, the great majority are derived from Silurian rocks, which form the main part of the Dividing Range. In the Werribee Gorge several kinds of slate occur, which are identical with slates found in the till. Quartz veins are also numerous in the Silurian rocks. We also noted a quartzitic sandstone in the Gorge, which is very similar to fragments found in the till. Several varieties of quartzite occur in the till which we have not yet seen *in situ*, but we have not yet examined the Ranges to the north, and it is very probable they will be found there as quartzites frequently occur in the Silurian. Fragments of schistose rocks have also been observed in the till, and these occur *in situ* to the north.

Several kinds of granite occur in the till. Granite is found *in situ* in the locality, and among the granite boulders some occur that seem identical with this granite. A very coarsely crystalline variety is also met with, the crystals of felspar being sometimes over an inch in length. Though we ourselves have not seen this in place, yet the Geological Survey report a granite with very large crystals of felspar as occurring in this locality. Pegmatite and aplite also are found in the till. As both of these may occur as veins in other granite, it would not be surprising if they have been overlooked. It is not unlikely even that they may be now concealed beneath the basalt that is well developed in this district.

Summing up, then, the results of our investigations, it would appear that two main points are clearly brought out. The first of these is, that there are two distinct glacial deposits; and the second, that both of these deposits are due to glacier ice, and not to icebergs—in fact, both being moraines profondes. Both are of similar character, except that the lower one is more indurated and jointed. Of these, the latter has been seen to closely enwrap the smoothed, grooved, and furrowed surfaces of Silurian rocks, of the glacier origin of which there can be no doubt. It is useless at this stage of geological inquiry to maintain that icebergs can produce roches moutonnées. A full discussion of this point may be read in Dr. Croll's "Climate and Time," Geikie's "Great Ice Age," and in "The Labrador Coast," by Dr. Packard. In connection with the upper till, though no undoubted roches moutonnées have yet been met with, yet, as we have seen, shattered rock surfaces below the till are found, which may be said to be quite as characteristic of the action of glacier-ice as a smoothed and moutonnée surface.

It now becomes a most important and interesting question to determine the respective ages of the two tills. It seems certain that we must look to astronomy for the explanation of ice ages. Dr. Croll's celebrated theory has, until now, notwithstanding considerable adverse criticism, been the most satisfactory explanation offered. Recently, however, Sir Robert Ball in his little work "The Cause of an Ice Age," has re-stated the astronomical theory, pointing out an error made by Croll. It would be beyond the scope of this present paper to enter into a discussion on the cause of ice ages, it will suffice to say that Sir Robert Ball has stated the case with great force and clearness. The theory as it now stands shows that when the astronomical conditions for the production of extensive glaciation arise, then we have a period during which several glacial epochs alternate with genial epochs between the two hemispheres, the length of each epoch being 10,500 years. The conditions for this state of things then gradually disappear, and do not occur again till after the lapse of long ages. Sir Robert Ball says he makes no attempt to state the date of the last glacial period, nor to say when the next is to take place. So, according to this theory, using the term "period" to embrace several glacial and genial "epochs," we should expect to find evidence of glaciation in both hemispheres during the same period, though not necessarily to the same extent, for of course the astronomical conditions for glaciation are liable to considerable modification by the existing distribution of land and sea, and the elevation of mountain chains.

Now, taking the case of our lower till first, we have seen that it is overlaid (apparently unconformably) by rocks which have been assigned to Lower Triassic age. In the Permian Period in the Northern Hemisphere, there are clear indications of a glacial epoch or epochs. In England, Dr.

Ramsay describes "brecciated conglomerates," consisting of "pebbles and large blocks of stone, generally angular, imbedded in a marly paste." Many of these stones are as well scratched as those found in modern moraines, or in boulder-clay. Similar boulder-beds occur in Scotland, Ireland, and Germany. Mr. Wallace ("Island Life") states that these physical indications are corroborated by a consideration of the life of the period, which is characterised by its poverty. In India, similar Permian boulder-beds occur, in which large striated stones and boulders are found. In one instance, the rock surface beneath this deposit was glacially scored and striated. These beds have been correlated with similar ones in South Africa, also of Permian age. Mr. G. W. Stow has, according to Dr. Ramsay, given elaborate accounts of these South African boulder-beds. He says that in Natal the great masses of "moraine matter" not only contain ice-scratched stones, but the underlying rocks are well rounded and mammilated, and covered by "deeply incised glacier grooves" in a direction that at last leads one to the pre-Permian mountains, whence the stones forming the moraines have been derived. In Natal, the striated rocky floor is only 30° south, and in India, only 20° north of the equator.

That evidence of severe glaciation should be found in the same period in both hemispheres, and so near the equator—being actually within the tropics in one case—is a strong argument in favour of the astronomical theory, betokening a much wider cause than mere local elevation. This being the case, we might expect to find traces of a glacial period during Permian times here in the more southern parts of Australia. The position of our lower glacial conglomerate, or till, is quite compatible with its being of Permian age, and when to this we add the considerations just noted, this conclusion is much strengthened. There is a strong break in the flora at the close of the Permo-carboniferous series in New South Wales (Prof. David, Address A.A.A.S., 1890). It is possible that this break may correspond with a Permian glacial period.

Now, as regards our upper till. We have not as yet been able to arrive at any very definite conclusion as to the age of this deposit. As we have seen, it lies on the denuded surface of the Triassic rocks, and is certainly overlaid by the Pliocene basalt. That it is also overlaid by the older basalt admits of little doubt, for although this basalt occurs in the locality, yet we have never found a trace of any volcanic material in the till. The same reasoning applies as to its relation to the Miocene leaf-beds that are well developed in the district. These beds consist for the most part of hard clay-ironstone, in which leaf and plant impressions are very numerous, and as a rule exceedingly well preserved. As we have not found any fragments in the till that in any way resemble the material of these beds, it seems highly probable that the upper till is pre-Miocene.

In Europe, we have evidence of glaciation in Eocene times. In the "Flysch" of Switzerland, huge erratics occur. One of these measured 105 ft. in length, 90 ft. in breadth, and 45 ft. in height (Croll, "Climate and Time," p. 305). Although the Eocene fossils, both in Europe and Australia, indicate a mild climate, yet, as has been pointed out by Croll and other eminent authorities, the life of a glacial epoch would be characterised by negative conditions. As it is of the very essence of the astronomical theory of ice-ages that glacial alternate with genial epochs, it is only to be expected that the life of the genial epochs would be the more likely to be preserved. So it is possible that out upper till is Eocene; this, however, we merely throw our as a suggestion, in the absence of any further evidence at present. Considering the great amount of erosion that took place in Upper Mesozoic and early Tertiary times, it seems improbable that this deposit is earlier than Eocene.

Mr. Stirling and Dr. Lendenfeldt have described undoubted evidences of glaciation in the Australian Alps. These gentlemen found glaciated surfaces on Mt. Cobberas at elevations between 6000 ft. and 4000 ft. above the sea, on Mt. Pilot, and on Mt. Kosciusco. Erratics of huge basaltic boulders occur in "linear extension for miles" in the Reewa River and Snowy Creek valleys, the nearest basaltic outliers being twenty miles away. Perched blocks of hornblende porphyrite occur on "crests of spurs and sidelings" in a regular descending series from near the summit of Mt. Bogong towards the Reewa valley, many of them resting on smoothed surfaces of pegmatite. Moraines occur at the base of Mt. Bogong, at 1000 ft. above sea level. Similar evidences of former glaciation have also been described by Mr. Stirling as occurring in the Livingstone valley, Parslow's Plains, and elsewhere in our Alpine regions.

There would seem to be no doubt that the glaciation indicated by these evidences in the Australian Alps is of much more recent age than that represented by the upper till at Bacchus Marsh. The presence of erractics of basalt, in "linear extension" along the valleys and on the slopes of the Alps is sufficient to show this. Dr. Lendenfeldt considered that this period of glaciation only terminated between 2000 and 3000 years ago, but, as Professor Hutton has shown, there is no evidence to sustain this. Professor Hutton has expressed the opinion that there was no evidence to indicate that the Southern Hemisphere had ever had a glacial period. That glaciers had formerly existed in the Australian Alps, he has explained on the hypothesis of a local elevation of the Alps, to about 3000 feet above their present level. Now this glaciation took place since Miocene times, as is shown by the basaltic erratics. Mr. Stirling has assigned it to the Pleistocene Period. It is impossible that it can be earlier, for if it were, the erractics would have long ago disappeared from their positions on mountain sides and spurs.

During the Pliocene Period we have evidence, in the distribution of marine gravels, of a submergence of nearly 1000 feet below the present level, and since then the land has gradually risen to its present condition (Murray). In his address to the Biological Section of the A.A.A.S., at Hobart, Professor Spencer says:—"We must conclude from the mammalian fauna, that there has been no absolute land connection between South-east Australia and Tasmania since practically the end of the Tertiary Period or early in Pleistocene times, as otherwise it would be impossible to account for the absence, not only of the dingo, but of the large and specialised diprotodont fauna, of which the Pleistocene Period saw the rise and fall upon the mainland." From the evidence supplied by raised beaches, and by the great depth to which many of our river channels have been cut, it is apparent that the land has been gradually rising for a considerable period. It is thus pretty certain that, since the beginning of Pleistocene times, the land surface has never stood higher, relatively to the sea, than it does now, and in Pliocene times, as we have seen, there was a submergence of nearly 1000 feet below the present level.

If denudation has been the means of reducing the height of our Alpine regions by about 3000 feet since the last glaciation took place, then it would be quite impossible for lines of erratic boulders and perched blocks on mountain spurs to be preserved. Many of these, according to Mr.

Stirling, even yet show striated and grooved surfaces. If the mountains had suffered much denudation, the striæ and grooves would certainly have been removed and roches moutonnées would have vanished—except where protected by overlying deposits—long ago.

So then, seeing that the theory of greater elevation cannot be sustained, we must look in another direction for the explanation, and we have the astronomical theory at hand. According to this theory, we should expect to find evidence of a Pleistocene glacial period here, corresponding with that of the Northern Hemisphere. As we have seen, this is the period to which Mr. Stirling has referred this latest glaciation of the Australian Alps. As eminent authorities have already observed, in trying to realize the probable effect of astronomical conditions favourable to glaciation in the Northern and Southern Hemispheres respectively, the great proportion of sea to land that now obtains in the south must always be borne in mind. The effect of this, in the present distribution of land and sea, would undoubtedly be to mitigate these conditions. In Pleistocene times, there is no evidence to show that our mountains were appreciably higher than now; it seems more probable that our land surface stood actually lower. So that the astronomical conditions which, during this period, resulted in producing such a severe glaciation in the Northern Hemisphere, were probably so mitigated in the Southern Hemisphere that glaciers only appeared in the higher mountains.

Mr. G. S. Griffiths, in a paper on the "Evidences for a post-Miocene Glacial Period in Victoria," describes heavy boulder washes, distributed in many parts of the Colony. These "washes" are ascribed to glacial action. Though the evidence for this is not conclusive, yet it is by no means improbable that these heavy deposits of boulders—many of them basaltic—were formed at the period of the last glaciation of the Alps, when the precipitation was much greater than now. The Dividing Range, except in its eastern parts, not being high enough for the production of glaciers, in the short hot summers of the epoch vast floods from melting snow swept down from the mountains, swelling the rivers and depositing these boulder beds.

At the two earlier periods of glaciation we have indicated, it is not improbable that there was a greater southward extension of land by way of Tasmania than now obtains. In Upper Palæozoic times, the Main Divide must have stood many thousand feet higher than it does now. In Eocene times, though enormous denudation had then taken place, this mountain chain must have been very much higher than now. Under these conditions, the glaciation during an ice age might be of considerable severity.

We would thus appear to have evidence of three periods of glaciation in Australia, which may be provisionally assigned as follows :—(1) One in Permian times, of considerable severity ; (2) one in Eocene times, also severe ; (3) one in Pleistocene times, mild, being represented only by glaciers in the higher mountains. At these periods then, it would appear that the Dividing Range nourished great glaciers which radiated outwards, and, in the two earlier periods at least, spread to some distance over the lower ground. Beneath these glaciers the till, or glacial conglomerate, was accumulated as a ground moraine.

Undoubted evidence of glaciation has been adduced by Professor Tate and Mr. G. B. Pritchard from South Australia, and traces have also been noted in Tasmania, although Mr. Johnston remarks ("Geology of Tasmania") that there is no evidence there to show that a glacial period has ever taken place. However, it will seem strange if further evidence from Tasmania be not forthcoming.

In concluding this paper, we would urge the careful examination and mapping of our glacial deposits, and the collection of all evidence bearing upon them. In the words of Sir Robert Ball—"A strict search for glacial indications among all deposits, primary, secondary, and tertiary, would be one of the most valuable pieces of scientific work possible at the present time."—("Cause of an Ice Age," p. 149).

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